Technical Note DOER-C6
May 1999

Manufactured Soil Screening Test

PURPOSE: The purpose of this technical note is to provide a screening test that can be used to evaluate the potential for manufacturing artificial soil using dredged material, cellulose waste materials (e.g., yard waste compost, sawdust, wastepaper), and biosolids (e.g., N-Viro-reconditioned sewage sludge, BIONSOIL-reconstituted cow manure). This procedure will allow the most productive blend of any dredged material (uncontaminated or contaminated), cellulose, and biosolids to be determined and recommended for use in an environmentally productive and beneficial manner.

BACKGROUND: Nonpoint and point source soil particles and other materials in runoff find their way to the bottom of waterways. These soil particles become sediment that eventually needs to be removed from the waterways to maintain navigation. The U.S. Army Corps of Engineers (USACE) is responsible for maintaining the Nation's navigable waterways and annually dredges approximately 400 million cubic meters of sediment. A small volume of this dredged material contains a wide range and level of contaminants, such as polynuclear aromatic hydrocarbons, polychlorinated biphenyls, pesticides, and metals. Dredged material that cannot pass stringent open-water disposal testing criteria requires confined disposal alternatives. Finding disposal sites for dredged material is becoming difficult, since most confined disposal facilities (CDFs) are at full capacity. Likewise, sewage sludge can no longer be disposed of in the ocean; consequently, sewage sludge is piling up on land at many sewage-treatment facilities. Also, large volumes of sewage sludge are currently placed in landfills; however, landfills are filling at accelerated rates. To resolve the accumulation and disposal of sewage sludge, the U.S. Environmental Protection Agency (USEPA) has issued 40 CFR Part 503 regulations (USEPA 1990, 1993). The 503 regulations promote the reuse of biosolids derived from sewage sludge and established maximum limits for metals in soils amended with biosolids derived from sewage sludge for agricultural production. These limits were based on risk-assessment evaluations (USEPA 1989). The manufactured soil technology offers a quick, simple, low technology and an effective and affordable means of allowing the reuse of dredged material, provides additional placement capacity for future dredged material by emptying many existing full CDFs, and recycles waste materials to the benefit of the American people.

INTRODUCTION: The Environmental Laboratory at the U.S. Army Engineer Research and Development Center, Waterways Experiment Station (WES), developed the manufactured soil technology using Cooperative Research and Development Agreements established with commercial companies. Cooperative Research and Development Agreements will enable manufactured soil technology to be developed and demonstrated at USACE confined disposal sites. Cooperative Research and Developments Agreements established or pending* are listed below:

Cooperating Company	Aspect of Manufactured Soil
BION Technologies, Inc.*	Reconditioned biosolids from cow manure
Recycled Soil Manufacturing Technology (formerly Terraforms)	Formulation and blending equipment
N-Viro International	Reconditioned biosolids from sewage sludge
Scott and Sons Company*	Bagged soil products

Several bench-scale screening tests have been conducted using uncontaminated dredged material from Toledo Harbor, Ohio, North Blakeley CDF in Mobile, Alabama, and St. Lucie Estuary, Florida; nutrient-depleted soils from Fort Drum; New York; sandy soil from the Herbert Hoover Dike surrounding Lake Okeechobee, Florida, and contaminated dredged material from the New York/New Jersey Harbor-Newtown Creek site (Lee et al. 1998; Lee and Sturgis 1996). These screening tests have been successful in determining the optimal percentages of dredged material, cellulose, and biosolids to manufacture a fertile soil product. Manufactured soil using uncontaminated dredged material can potentially be used without restrictions as topsoil, while artificial soil manufactured from contaminated dredged material may have restricted use (e.g., potential cover for landfills, superfund sites, and reclamation of mineland) depending on the level of contamination and the potential for contaminant release. The fertile soil product manufactured from dredged material has been shown to contain lower levels of contaminants than the original dredged material because of the dilution of material in the blend. Table 1 shows an example of a manufactured soil blend that contains total metal concentrations below specified acceptable limits of the USEPA 503 regulations for biosolids-amended agricultural soils. Adding organic waste material to the manufactured soil product appears to bind and immobilize the contaminants reducing their bioavailability. The quality of manufactured soil with respect to contaminant content will determine the final use of the manufactured soil product.

Table 1
Example of Dredged Material and Blend Metal Concentrations, mg/kg

Analytes	Dredged Material	Blend	USEPA 503 Regulation
Zinc	1,752.0	514.0	2,800.0
Cadmium	37.0	7.9	39.0
Lead	617.0	231.0	300.0
Copper	1,172.0	393.0	1,500.0
Chromium	377.0	140.0	
Mercury	1.3		17.0
Silver	18.4	6.1	
Arsenic	33.5	12.5	41.0
Beryllium	<0.6	<0.3	
Nickel	297.0	95.0	420.0
Antimony	10.3	2.1	
Selenium	3.2	3.3	
Thallium	<2.8	<1.6	

BENCH-SCALE SCREENING TESTS: A specific blend (e.g., x_1 percent dredged material, y_1 percent cellulose, and z_1 percent biosolids) can be prepared by mixing predetermined volume percentages of cellulose, biosolids, and dredged material. Different blends are made by decreasing the volume percentage of dredged material and increasing the appropriate volume percentage of cellulose and biosolids. For the manufactured soil technology to be successful, the recommended

blend must support plant growth and reduce the bioavailability of contaminants. The productivity of the manufactured soil can be demonstrated by evaluating seed germination and plant growth of *Lycopersicon esculentum* (tomato), *Catharanthus roseus* (vinca), *Tagetes patula* (marigold), and *Lolium multiflorum Lam.* (ryegrass) grown in replicated 10-cm pots under controlled greenhouse conditions. Temperature in the greenhouse should be maintained at 32.2 ± 5 °C during the day and 21.1 ± 5 °C minimum at night. Relative humidity should be maintained as close to 100 percent as possible, but never less than 50 percent. Emerged seedlings can be counted after 14 and 21 days to determine seed-germination percentages. Plant seedlings can then be allowed to grow and develop an additional 4 weeks to evaluate plant growth and appearance. Tomato, vinca, marigold, and ryegrass (four annual plant species) were selected because they are sensitive to salt, metals, and nutrient imbalances and represent a wide spectrum of upland plants (Raven, Evert, and Eichorn 1986).

Seed germination is important because the new plant starts as an embryo within the developing seed. Therefore, the seed occupies a critical position in the life history of the plant. The success with which the new plant is established is largely determined by the physiological response of the seed to its environment (e.g., dredged-material salt content). The movement of water from dredged material to seeds and uptake are essential steps toward seed germination. Some dredged material with its high bulk density decreases capillary water and vapor movement toward the seed, which in turn could result in decreased imbibition or physically restrict the swelling of the seed, thus possibly impeding seed germination (Hagon and Chan 1977). The blend fertility and contaminant levels usually do not directly affect seed germination, but may adversely affect the plant seedlings after germination and subsequent plant growth. Therefore, the plant physiological responses to various blends can be evaluated by using additional end points such as visual observations of leaf color, size, and shape as well as total aboveground biomass after weeks of growth and exposure to the blends.

Inferences as to the productivity of a particular blend can be made by statistically comparing percent seed germination and plant biomass from the different blends to the percent seed germination and plant biomass observed from the fertile reference soil (Tables 2 and 3; Figure 1). Table 2 shows a typical manufactured soil screening test experimental design.

Seed Germination. An example of typical results from a greenhouse bench-scale test and interpretation of data is presented in Figure 1 and Table 3. An evaluation of the statistical analysis showed that seed germination was influenced by treatment ($P = 0.0001$), species ($P = 0.0001$), and time ($P = 0.01$). P is the probability used as the criterion for rejecting the null hypothesis (H_0). For an example, if "H_0:good germination is influenced by treatment" is a true, it will be erroneously concluded to be false 0.01 percent of the time when $P = 0.0001$. Data analysis also revealed a treatment-species interaction ($P = 0.0001$). Seed germination in the fertile reference control (Blend 5) was significantly higher ($P < 0.05$) than seed germination in Blends 1, 2, 3, and 4 (Table 3). For example, tomato showed a 77-percent seed germination in Blend 2 compared with 83 percent in Blend 5, while marigold showed a 77-percent germination in Blend 2 compared with 93 percent in Blend 5. However, seed germination in Blend 2 with Toledo Harbor Cell 1 dredged material was significantly higher than Blends 1, 3, and 4 using Toledo Harbor dredged material as an ingredient. Although Blend 2 showed the best percent germination (64 percent) overall, ryegrass percent seed germination was higher in Blend 3 than Blend 2 (Table 3). There

was no difference between percent ryegrass seed germination in Blend 3 and ryegrass seed germination in Blend 5. Seed germination was in the order of ryegrass > tomato > marigold > vinca. Results after 21 days paralleled results obtained in the 14-day germination test. This suggests that ryegrass may be more efficient in taking up water. In addition, it also shows that ryegrass seed may be able to complete germination at lower water contents than tomato, marigold, and vinca.

Table 2
Typical Bench-Scale Screening Test Experimental Design

Treatments
Blend 1: Dredged material (100 percent)
Blend 2: Dredged material x_1 percent + Cellulose y_1 percent+ Biosolids z_1 percent
Blend 3: Dredged material x_2 percent + Cellulose y_2 percent+ Biosolids z_2 percent
Blend 4: Dredged material x_3 percent+ Cellulose y_3 percent + Biosolids z_3 percent
Blend 5: Fertile reference soil (control)

Plant Species
1. *Lycopersicon esculentum* (Tomato Big Boy)
2. *Tagetes patula* (Marigold)
3. *Lolium multiflorum Lam.* (Ryegrass Gulf Annual)
4. *Catharanthus roseus* (vinca)

Experimental Design
Seed germination test
5 treatments × 4 species × 4 replicates completely randomized block design
5 × 4 × 4 = 80 pots (10-cm-diam pots)
Plant growth test
5 treatments × 4 species × 4 replicates completely randomized block design
5 × 4 × 4 = 80 pots (10-cm-diam pots)

Table 3
Percent Seed Germination from Manufactured Soil Using Toledo Harbor Dredged Material from Cell 1

Blends	Tomato		Marigold	
	14 Days	21 Days	14 Days	21 Days
5	83.3 ± 2.4	86.7 ± 2.4	93.9 ± 2.3	93.3 ± 2.3
4	6.7 ± 2.4	10.0 ± 4.1	26.7 ± 2.4	30.0 ± 4.1
3	10.0 ± 4.1	26.7 ± 6.2	63.3 ± 8.5	76.7 ± 8.5
2	76.7 ± 8.5	86.7 ± 2.4	76.7 ± 9.5	93.3 ± 2.4
1	0.0 ± 0.0	13.3 ± 4.7	6.7 ± 4.7	10.0 ± 7.1
Blends	**Ryegrass**		**Vinca**	
	14 Days	**21 Days**	**14 Days**	**21 Days**
5	91.7 ± 1.2	91.7 ± 1.2	40.0 ± 7.1	60.0 ± 8.2
4	68.3 ± 9.4	70.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
3	86.7 ± 1.2	91.7 ± 1.2	3.3 ± 2.3	3.3 ± 2.3
2	80.0 ± 0.0	86.7 ± 3.1	3.3 ± 2.3	23.3 ± 5.3
1	80.0 ± 5.8	90.7 ± 7.1	0.0 ± 0.0	3.3 ± 2.3

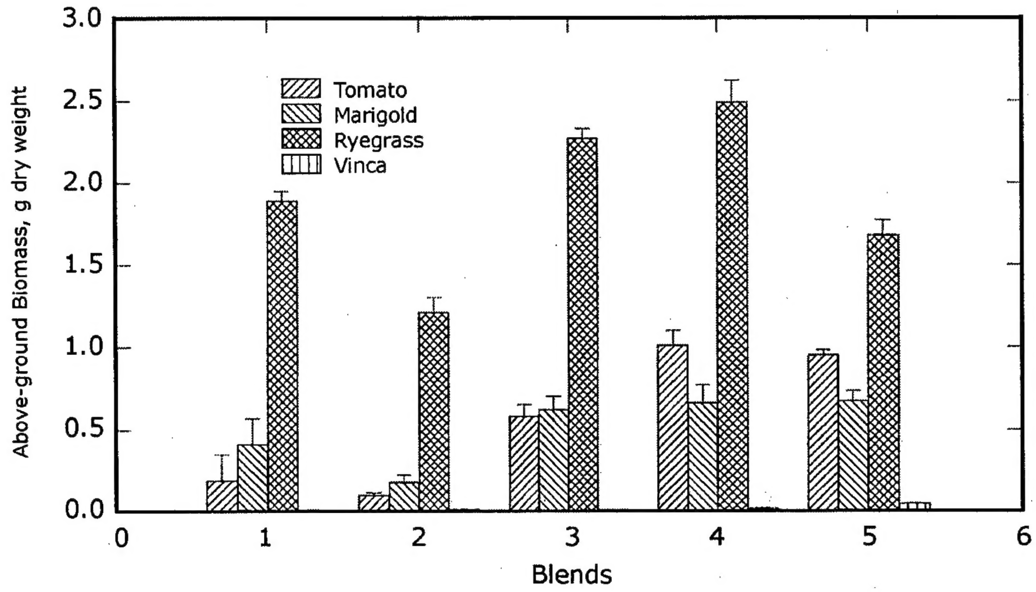

Figure 1. Total aboveground plant biomass collected from the various Toledo Harbor dredged-material blends

Differences observed in seed germination among the different blends could be due to factors (e.g., salinity, substrate) affecting the rate and extent of water movement from the manufactured soil blend to the seeds. The additional time significantly enhanced seed germination. For example, in Blend 2 after 21 days tomato showed a 10-percent increase in seed germination; marigold showed an increase of 16 percent; ryegrass increased 7 percent; and vinca had the largest increase of 20 percent.

Plant Growth. Total aboveground biomass determination (quantitatively) and visual observations (e.g., leaf color, size, and shape) are means of evaluating the fertility of the manufactured soil blend. Though visual observations are not quantitative, they can provide useful information concerning the blend fertility (Figures 1, 2, and 3). For example, the most easily observed symptom of nitrogen deficiency is the yellowing (chlorosis) of leaves because of a reduced chlorophyll content. This symptom is usually noticed first in the more mature leaves and last in the more actively growing leaves. Under severe conditions of nitrogen deficiency, the lowermost leaves on plants will be dry and yellow and often abscise.

Phosphorus may cause premature leaf fall and purple or red anthocyanin pigmentation. Unlike plants lacking nitrogen, plants lacking phosphorus may develop dead necrotic areas on the leaves and petioles; or they may have a general overall stunted appearance, and the leaves may have a characteristic dark to blue-green coloration. Zinc and phosphorus deficiencies in a blend may cause a distortion in the shape of leaves of some plants. Calcium affects the meristematic region of the stem, leaf, and root tips; these areas usually die, thus terminating growth in these organs. Chlorosis generally occurs along the margins of younger leaves. These areas usually become necrotic.

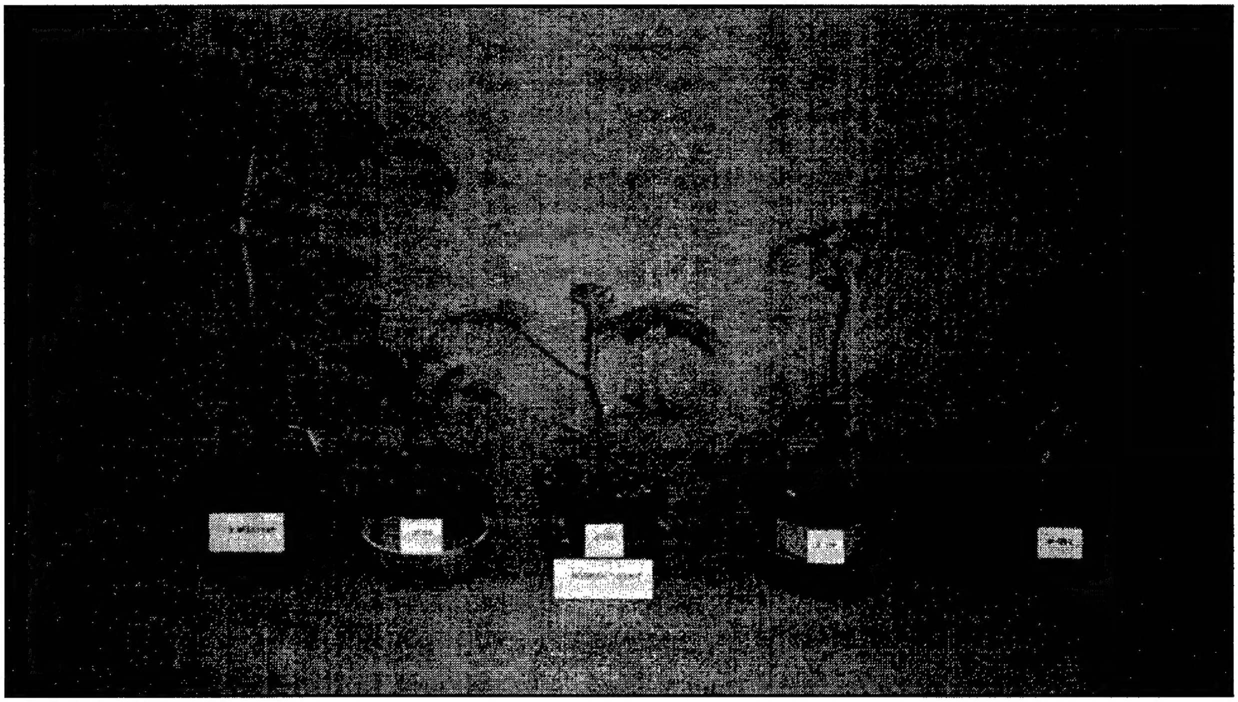

Figure 2. Tomato plants growing in the different manufactured soil blends (left to right, Blends 1, 4, 3, 2, and 5

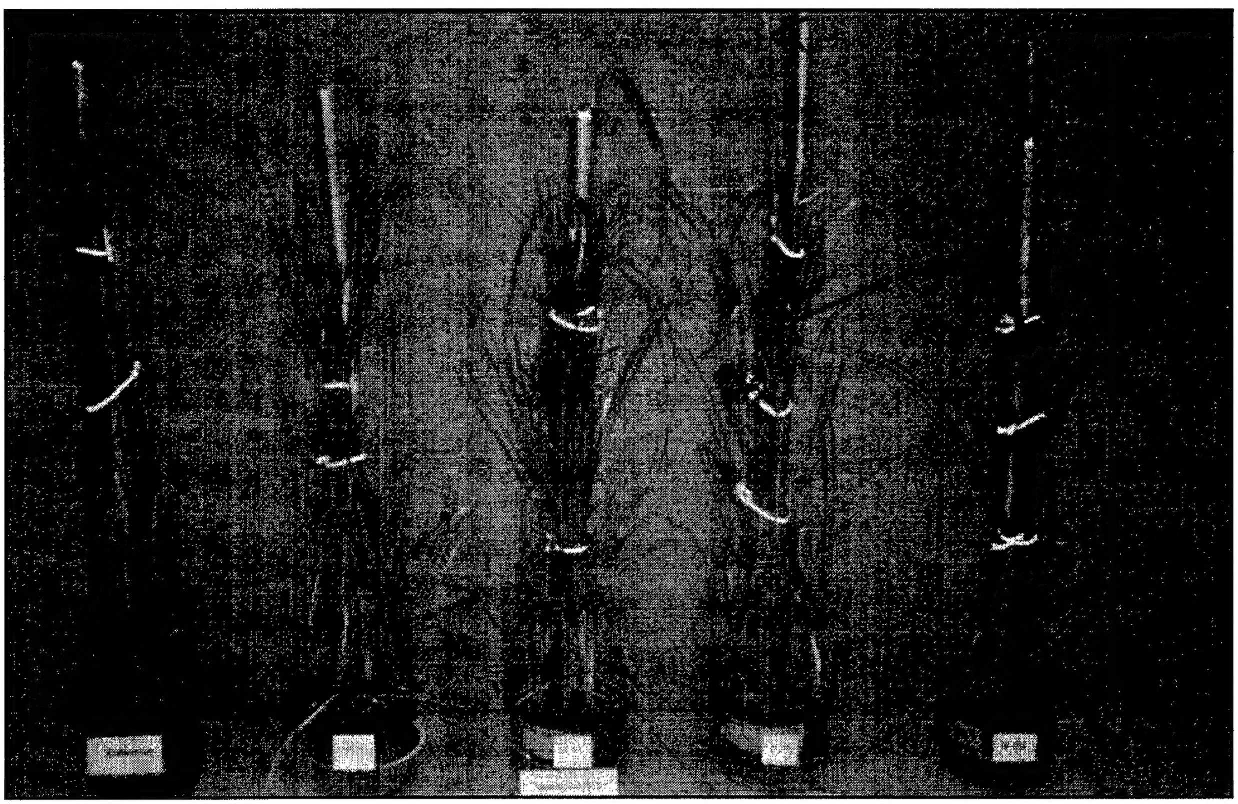

Figure 3. Ryegrass plants growing in the different manufactured soil blends (left to right, Blends 1, 4, 3, 2, and 5

Malformation or distortion of the younger leaves is also a characteristic feature of calcium-deficient plants, a hooking of the leaf tip being the most easily detected symptom. Magnesium deficiency in green plants is extensive interveinal chlorosis of the leaves. Excessive salt in dredged material and/or blend will inhibit plant growth by decreasing water availability to the roots and inhibiting physiological processes that require water (Lee et al. 1985). Excessive salt may cause leaf epinasty (downward curving of the leaf blade), chlorosis, and death.

A case study involving dredged material from Toledo Harbor CDF Cell 1 will be presented to illustrate how visual observations may be applied during a manufactured soil screening. Visual observations, during the first 2 weeks, of leaf color, size, and shape revealed similarities between plants growing in Blend 4 and plants growing in Blend 5 (fertile reference control). However, at Day 21, plant growth in Blend 4 seemed slower than plant growth in Blend 5. Leaf color gradually changed from green to yellow, and the leaves were not as broad as the plants growing in the fertile reference control (Figures 1, 2, and 3). Yellow color and narrow leaves were ascribed to nutrient deficiency in the manufactured soil blend. On Day 22, soluble ammonium-nitrate and Miracle Gro™ (13N-13P-13K) were added to all of the Toledo Harbor dredged-material blends. The addition of nutrients to the blends appeared to have enhanced plant growth. At the end of 7 weeks, visual observations of leaf color, size, and shape revealed similarities between plant species growing in Blend 4 and plant species growing in Blend 5 (Figures 1, 2, and 3).

Ryegrass, tomato, and marigold grew better in Blend 4 than plants in Blends 1, 2, or 3 (Figure 3). The total aboveground dry weight biomass obtained from Blend 4 was significantly higher than the total aboveground biomass from Blend 5 (fertile reference control).

The results from the screening tests indicated that Blend 4, consisting of Toledo Harbor dredged material, cellulose, and biosolids, will enhance plant growth. It was concluded that a high-quality manufactured soil product could be blended using Toledo Harbor dredged material. Soil fertility analysis and physical characterization of the blend was conducted. Commercialization of this manufactured soil process has been initiated. A field demonstration was successfully conducted to produce 550 cu yd of fertile topsoil. This manufactured topsoil was used to landscape the entrance to the University of Toledo and improve soil beds at the entrance of the Toledo Botanical Gardens (Figures 4 and 5).

SUMMARY: Since manufactured soil is new, innovative, and in its infancy stage, caution should be used in applying this technology. The technology affords a practical means of promoting the reuse of uncontaminated and even contaminated dredged material and the Nation's organic waste material. The evaluation of the feasibility of manufacturing a productive soil product from dredged material should include a two-phase approach. Phase 1 should include the bench-scale screening evaluations for seed germination and plant growth and the physical and chemical characterization of the dredged material and blend. If the screening tests show that the dredged material can potentially be used to manufacture a fertile soil product, then a second phase, either a demonstration project using the blend identified in the bench-scale tests could be conducted or commercialization of the process could be initiated.

The manufactured soil technology is site specific. The optimal blend for a specific dredged material will depend on the physical and chemical characteristics of that dredged material and the available

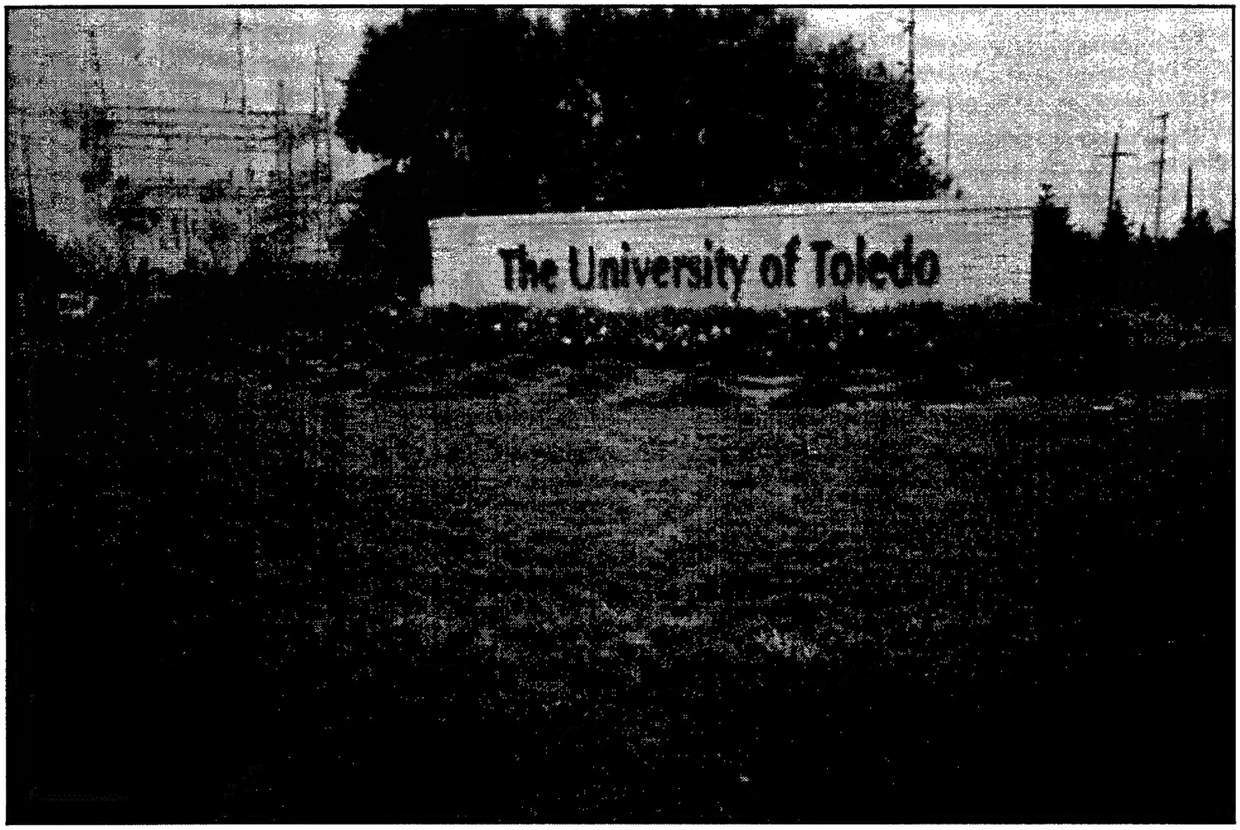

Figure 4. Landscaped entrance to University of Toledo

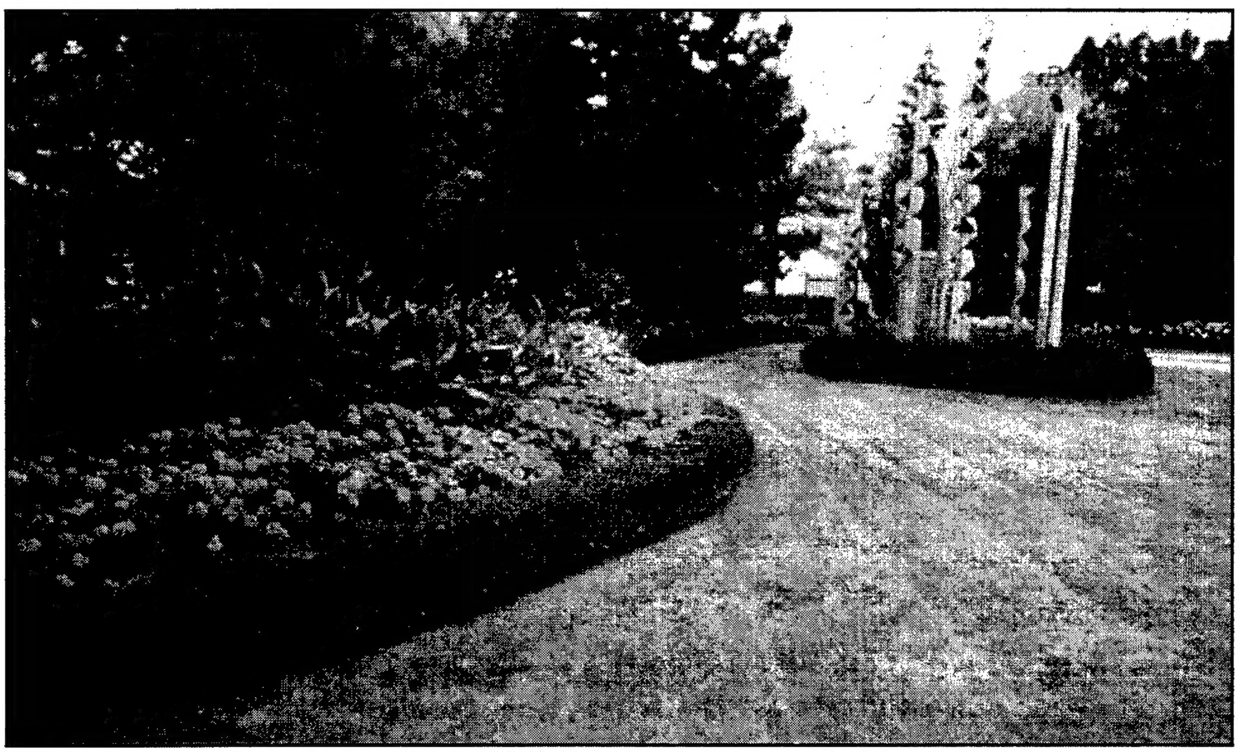

Figure 5. Landscaped bed to entrance of Toledo Botanical Gardens

cellulose and biosolids at that location. The blend found productive for one site may not hold for dredged material, cellulose, and biosolids from other sites. Therefore, bench-scale screening tests at a minimum should be conducted on individual dredged material. In order to apply the manufactured soil technology described in this technical note, appropriate WES scientists should be contacted and/or a license should be obtained from Mr. Paul Adam, the inventor of patented manufactured soil technology.

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